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Recent Advances in PCS Antenna Design and Measurement

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Original scientific paper

Mobile communications are taking more and more importance in everyday life, creating the need for smaller and lighter mobile terminals. Unlike the electronic circuits, the size of an antenna is not technology related, but imposed by the wavelength of a given application. This makes antenna miniaturization to an art of compromise between size and radiation performances.

In this presentations we will first state the limitations of antenna miniaturization, by reminding of the well known laws linking gain, bandwidth and antenna size. Then some well known ways to reduce antennas sizes will be reviewed and illustrated on a practical example designed and realized in our laboratory. Finally, we will deal with the non trivial problem of small antenna measurement: the problems encountered when measuring small antenna will be presented and some clues on how to proceed correctly will be given.

Key words: mobile communications, electrically small antenna, antenna measurement

1 INTRODUCTION

Mobile communication have become an important part of telecommunications. Original applications like paging, mobile phones or GPS have shown a tremendous growth, and new applications are emerging every day: tagging, wireless computer links, wireless microphones, remote control, wireless multimedia links, satellite mobile phones, wireless internet, all these applications create the need for efficient and small mobile terminals.

This development linked to the fast paced evolution in microelectronic and battery technologies has allowed the emergence of smaller, lighter and more powerful handsets, creating the need to miniaturize antennas in the same way. Unfortunately, the size of the antenna of a transmission link is not technology related, but set by the laws of physics: the antenna's size is given by the wavelength of the application. Thus, antenna miniaturization is engineered using a very different strategy than circuit miniaturization: it is an art of compromise, where the best possible tradeoff between antenna size and characteristics has to be found for a given application.

In this paper, we will first briefly remind the well known rules linking an antenna's maximum performance to its size relative to the wavelength. We will then review some design strategies for miniature antennas, and try to give some physical insight into the effect of a given miniaturization technique on performances. An example of miniature antenna will also be shown, and the paper will close on some consideration on the measurement of small antenna performances.

2 PHYSICAL LIMITATIONS ON SMALL ANTENNAS

The relation between antenna size and performance has been of interest since many years [1–7], especially the link between size and maximum bandwidth and the link between size and gain. The former was first investigated by Wheeler [1] and Chu [2] in the late forties, the latter yielding the classical relation for the minimum quality factor of an antenna using a ladder circuit decomposition. This approach was enhanced by McLean [4] who used a rigorous decomposition of the field in spherical waves to obtain for a linear polarization:

$$Q_{\min} = \frac{1}{ka} + \left(\frac{1}{ka}\right)^3 \tag{1}$$

where a is the radius of the smallest sphere including the antenna and k is the wave number. For a large value of Q (which is usually the case for small antennas, the 3 dB bandwidth is equal to:

$$B_{3\text{dB}} = \frac{1}{Q}. \tag{2}$$

The concept of maximum possible gain of a small antenna has to be understood in a little different way, as was very clearly shown by Harrington [7]. Indeed, the gain of even a very small antenna can be made very large by exciting many spherical wave modes. But the near field energy stored in these higher order modes becomes very high, yielding a very small bandwidth for the antenna. The relation between gain and antenna size proposed by Harrington has thus to be understood as the relation giving the maximum gain of the small antenna having still a bandwidth of practical use:

$$G = (ka)^2 + 2ka. \tag{3}$$

The bandwidth and the gain obtained by these relation are upper limit, which is by no means easy to reach. They are a great help to the small antenna designer, by telling him when he is close to optimal performances with his antenna.

3 DESIGN STRATEGIES AND EXAMPLES

Small antenna design strategies have been of interest since many years, and documented in many publications and textbooks [9–13]. Electrically small antennas were first used at radio frequencies, were the wavelength is so large that resonant antennas could not be considered [10–12], and many of the ideas developed in this context can also be used for mobile terminal antennas, along with more dedicated concepts [8, 9, 13].

In general, miniaturization techniques can be divided in five categories, which are used separately or together in the design of a small antenna:

- antenna loading,
- geometrical loading using bends, slots and notches,
- using image theory through short circuits and ground planes,
- using the antenna's environment, and
- using multifrequency antennas.

The antennas of the last category are not necessarily small, but space is saved by putting two or more antennas in one. The effect of these techniques on antenna performances are described in [14, 15].

3.1 Miniature dual-band GSM antenna

Multifrequency antennas are of great interest for mobile communications, as base stations and terminals tend to combine more and more applications (like for instance GSM, DCS, Bluetooth, W-LAN, etc.) in one. Some examples of multifrequency antennas for different applications can be found in [16–22].

The example presented here is an miniature dual band single feed antenna for a GSM/DCS (900 MHz/1800 MHz) terminal [23]. The entire handset had to fit in a cylinder of 35 mm in diameter with a height of 8 mm, we chose thus to conform the antenna around the cylinder. This example is interesting, because several of the miniaturization means described above are used: Multifrequency, geometrical bending, short-circuits and the antenna environment. The design selected was a conformed PIFA, which is very efficient with narrow ground planes [24] and shows good performances for single frequency bands [25].

The single band conformed and integrated PIFA, called SMILA (SMart Integrated L Antenna) is shown on Figure 1.

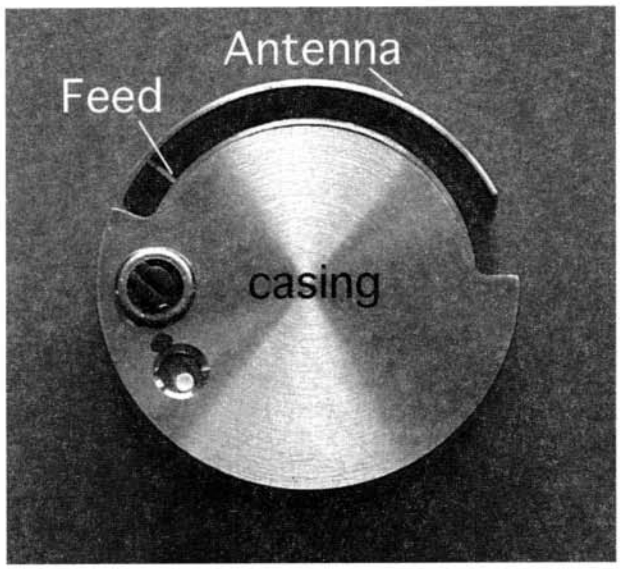

Fig. 1 Single band SMILA

To get dual band behavior, a bandstop filter tuned at the higher frequency band was inserted in the antenna arm, as is depicted in figure 2 for a

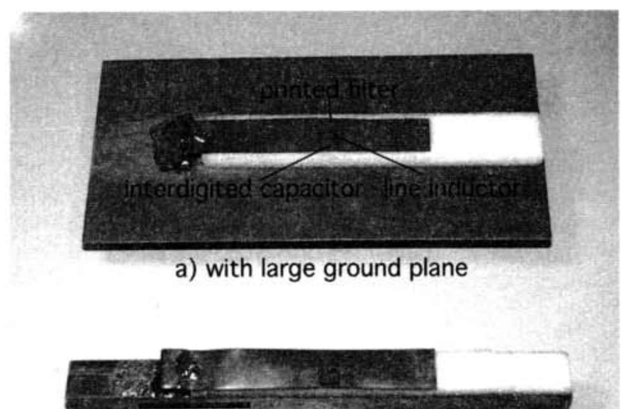

Fig. 2 PIFA with an integrated bandstop filter

non conformed case. The measured S_{11} for both antennas are presented in figure 3. The dual band behavior is clearly shown, and, as was expected for a PIFA like antenna, the case with narrow ground plane gave a broader bandwidth.

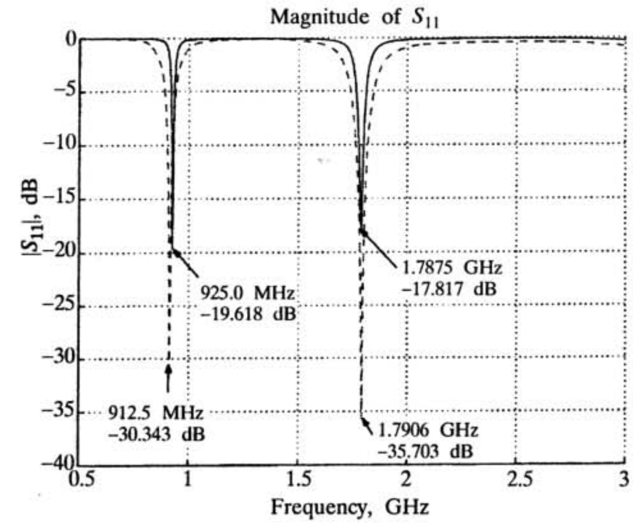

Fig. 3 S_{11} of the two planar dual band PIFAs. The full line corresponds to the large ground plane, the dotted line to the narrow ground plane

This concept was used on a conformed PIFA, as is depicted in figure 4.

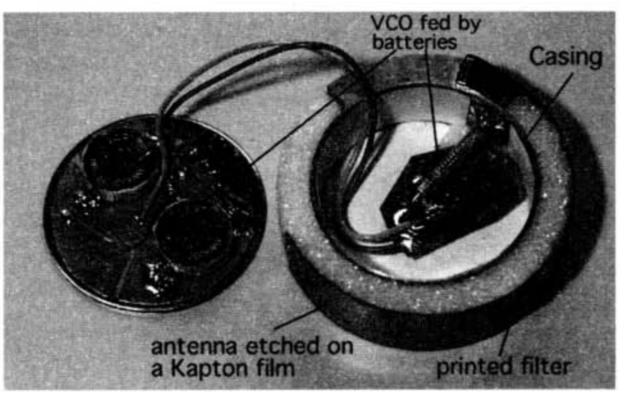

Fig. 4 Conformed dual band PIFA, with casing and VCO feed

The performances of this antenna were measured using the small antenna gain measurement setup described in §4, and the following gains were measured:

- 1.9 dBi at 935 MHz, where the antenna has a size of $\lambda/10$ and maximum practical gain after Harrington's formula is –0.7 dBi
- 1.5 dBi at 1.8 GHz, where the antenna has a size of $\lambda/5$ and maximum practical gain after Harrington's formula is 2.8 dBi.

The antenna was optimized for the lower band, which is more critical for an antenna of this size. Both the SMILA and the dual band conformed PIFA are patented [26, 27].

4 SMALL ANTENNA MEASUREMENT

Measurement of electrically small antenna is far from trivial. This comes from the fact that in most of cases, an electrically small antenna is neither symmetric nor asymmetric. This is best understood on the example of a microstrip patch antenna. On an infinite ground plane, this is clearly an asymmetric antenna and should be fed by an asymmetric feeding line. But when the ground plane is cut, so that the antenna becomes smaller, this is no longer true. Indeed, at the limit the ground plane can be of the same size as the antenna, which would become symmetric and should be fed by a balanced feed. Most cases will be somewhere in between. The characterization of an electrically small antenna is much affected by this fact, as is explained in figures 5 and 6. In this example, we take the extreme case of a dipole (symmetric) fed through a coaxial cable (asymmetric) with no balun in between.

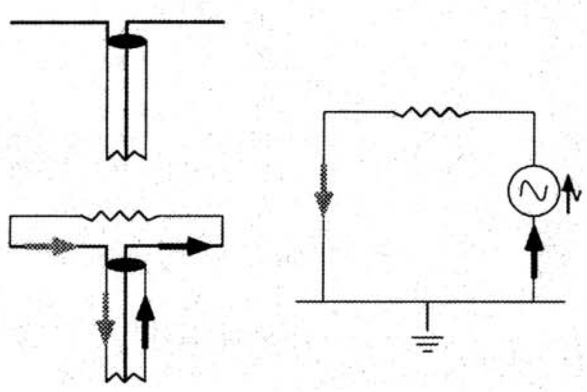

Fig. 5 Dipole fed through a coaxial cable and its equivalent circuit

The asymmetric source of the equivalent circuit can be split into two sources, a symmetric one and a non physical one depicted in figure 6.

As is clearly shown on figure 6, the currents due to the symmetric feed will yield a clean pattern, as the currents on the feed line cancel. However, the currents due to the unphysical source will on one hand induce spurious radiation from the cable and on the other hand destroy the current symmetry on the dipole, thus distort the radiation pattern.

The behavior of electrically small antenna will be similar [28]: spurious currents will flow on the outside of the coaxial cable which links the antenna to

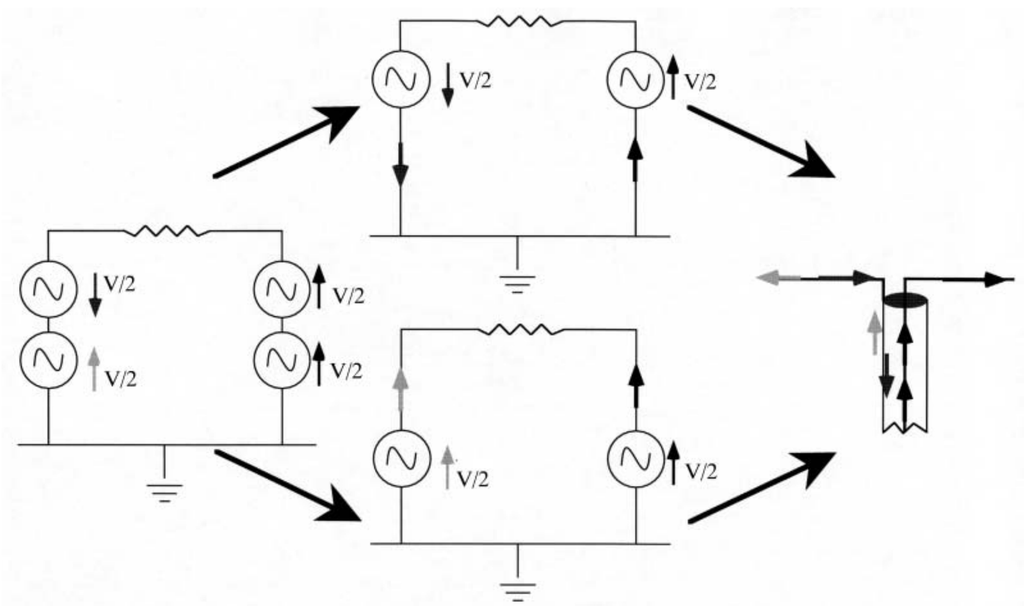

Fig. 6 Decomposition of asymmetric feed into a symmetric and an unphysical feed

the measurement instruments, causing spurious radiation. For a very small antenna, this parasitic radiation can be orders of magnitude greater than the antenna radiation itself, thus the measurements obtained will be erroneous: for instance, errors up to 10 dB can be made on gain measurement.

In order to correctly measure the radiation characteristics of an electrically small antenna, following rules should be followed:

– avoid the use of cable
– measure the antenna on its final casing, as the latter will participate to radiation.

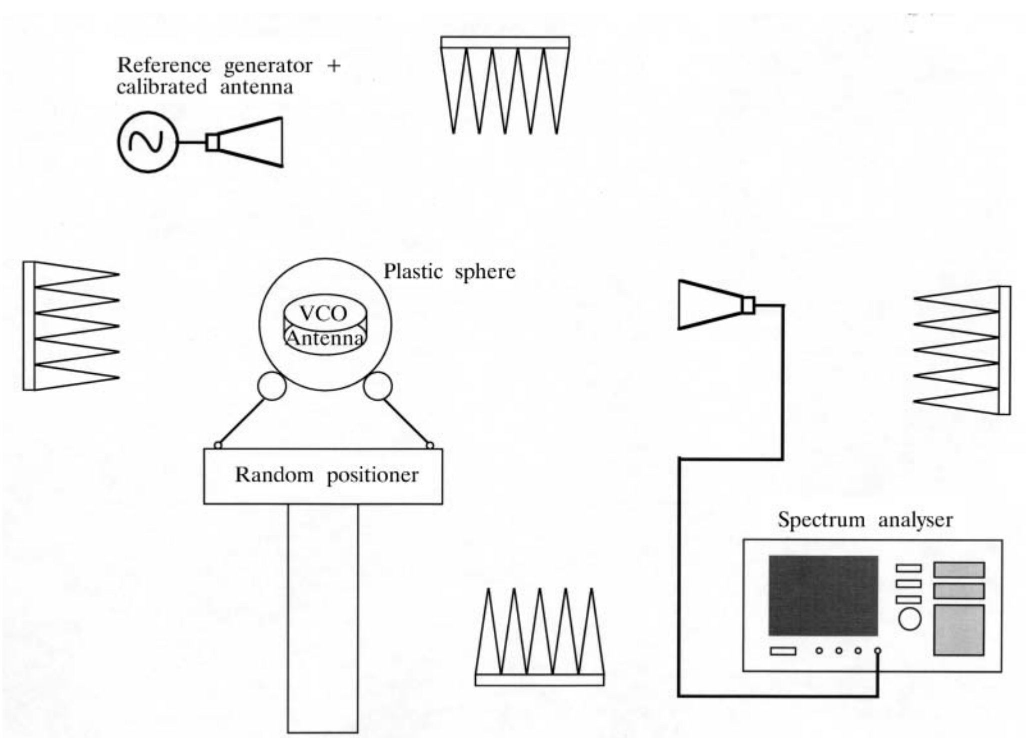

Fig. 7 Measurement set up

A measurement system following these rules has been set up in the anechoic chamber of our lab [29, 30]. It allows to measure both the maximum gain and the efficiency of an electrically small antenna. The system, depicted in Figure 7, consists of a random positioner allowing to move the antenna and its casing in any direction (azimuth, elevation and polarization). The antenna is fed by a VCO inside the casing, and is thus emitting. The receiving antenna is connected to a spectrum analyzer which records the maximum power received (for peak gain measurement) or the mean power received (for efficiency measurements). The antenna under test is then replaced by a known antenna (a dipole for instance) fed by known power, and the maximum gain or the efficiency are obtained by comparison. Note that the random positionner is made using only dielectric materials, the only metallic part being an electrical motor located at the bottom end of its foot.

The random positioner is depicted in Figure 8, with a blowup of the compressed air motor in Figure 9.

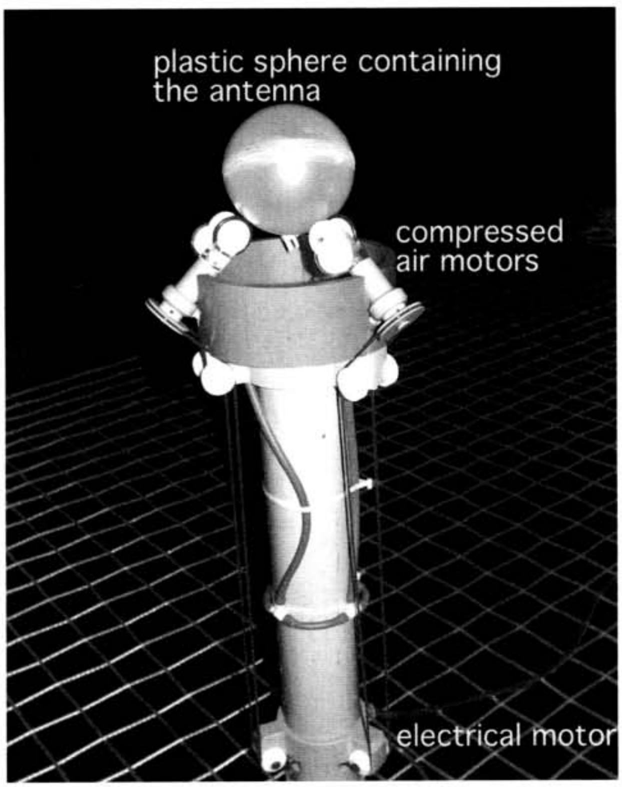

Fig. 8 Random positioner

The antenna under test powered by VCO (as for instance the antenna of Figure 4) is placed into the plastic sphere. The latter is randomly rotated by the 3 compressed air motors, which are rotated at different speeds by three belt driven by the electrical motor situated in the foot of the positionner.

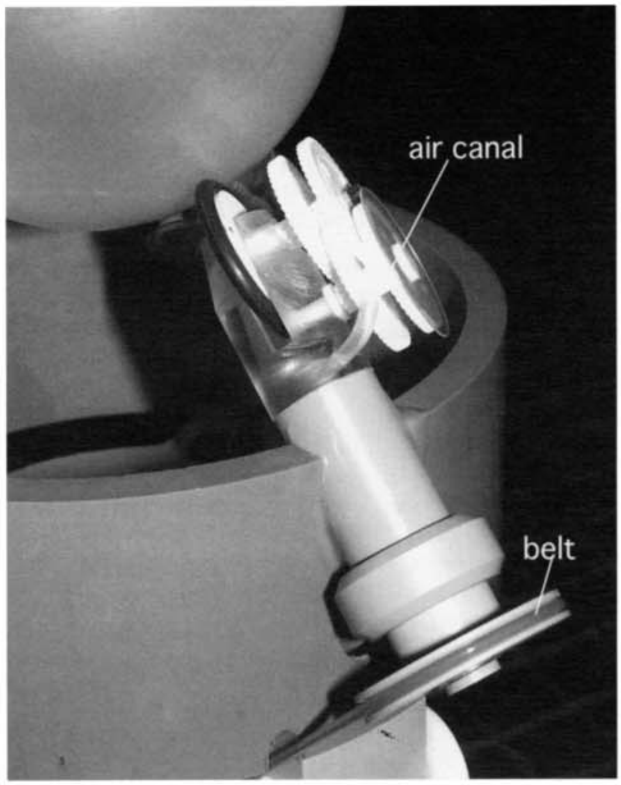

Fig. 9 Compressed air motor

To obtain the maximum gain of the antenna under test, the random positioner turns the antenna until the maximum received power is detected by the spectrum analyzer. The Antenna under test is then replaced by a reference antenna which is powered in order to reach the same level on the spectrum analyzer. The maximum gain of the antenna under test is then given by:

$$G_{\mathrm{AUT}} = P_{\mathrm{ref}} - P_{\mathrm{VCO}} + G_{\mathrm{ref}} \qquad (4)$$

where G_{AUT} is the maximum gain of the antenna under test. P_{VCO} the known power delivered by the VCO, P_{ref} the known power delivered to the reference antenna and G_{ref} the gain of the reference antenna. The accuracy of the measurement is of ± 0.5 dB, and depends mainly on the stability of the VCO and the precision of the reference antenna. The output power of the VCO is checked before and after the measurement in order to avoid errors due to drift.

The efficiency of the antenna under test is obtained by measuring the mean power emitted during rotation on the random positioner. We know that the efficiency of an antenna is equal to

$$\langle g(\theta,\varphi)\rangle = \frac{1}{4\pi}\int_0^{2\pi} \mathrm{d}\varphi \int_0^{\pi} \mathrm{d}\theta \sin\theta\, g(\theta,\varphi) = \\ = \frac{1}{4\pi}\int_0^{2\pi} \mathrm{d}\varphi \int_0^{\pi} \mathrm{d}\theta \sin\theta\, 4\pi \frac{u(\theta,\varphi)}{P_f} = \eta \tag{5}$$

where $g(\theta,\varphi)$ is the gain, $u(\theta,\varphi)$ is the radiation intensity and P_f is the total power fed to the antenna.

After some time of rotation, we can assume that the mean value of the radiation intensity measured over time is equal to the mean value time over space (azimuth, elevation and polarization, as the positioner has three axes). The efficiency of an antenna is equal to the mean value of the gain over azimuth and elevation, which in turn can be obtained from the measured mean value over azimuth, elevation and polarization knowing the maximum gain already measured and the mean power measured using the following relation:

$$\eta = \langle g \rangle = \frac{1}{F_{\mathrm{pol}}} \cdot \frac{g_{\max}}{P_{\max}} P_{moy} \tag{6}$$

where F_{pol} is the correction factor taking into account the fact that during the measurement of the mean power rotation was also performed over the polarization angle. It is easily shown using elementary trigonometry that for a linearly polarized antenna $F_{\mathrm{pol}} = 0.5$, whereas for a circularly polarized antenna $F_{\mathrm{pol}} = 1$.

The accuracy obtained with this measurement method is of 5 %, and depends critically on the precision with which the reference antenna is known.

5 CONCLUSION

A miniature dual frequency single feed antenna has been shown, in order to illustrate some ways of making antennas electrically small. A new, rigorous measurement system dedicated to the characterization of radiation properties of small antennas has been set up and presented.

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Novi rezultati u projektiranju i mjerenju antena za osobne pokretne komunikacije. Pokretne komunikacije postaju sve važnije u svakodnevnom životu, a time se povećava potreba za što manjim i lakšim pokretnim komunikacijskim uređajima. Za razliku od elektroničkih sklopova, veličina antene nije određena stupnjem tehnološkog razvoja već je zadana frekvencijskim područjem koje se koristi za određenu primjenu. Zato je minijaturizacija antena umjetnost kompromisa između malih izmjera i dobrih osobina zračenja.

U ovom su radu ograničenja minijaturizacije antena prikazana kroz povezanost dobitaka, širine pojasa i izmjera antene. Zatim su opisani neki uobičajeni postupci za smanjivanje izmjera antena. Njihova je primjena prikazana na praktičnoj izvedbi koja je projektirana i izrađena u našem laboratoriju. Konačno se razmatraju problemi pri mjerenjima malih antena: izneseni su problemi koji su uočeni pri mjerenju malih antena kao i naputci za njihovo prevladavanje.

Ključne riječi: pokretne komunikacije, električki mala antena, antenska mjerenja

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